# Anomalous low-velocity zone and linear alignment of seismicity along it in the subducted Pacific slab beneath Kanto, Japan: Reactivation of subducted fracture zone?



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# Anomalous low-velocity zone and linear alignment of seismicity along it in the subducted Pacific slab beneath Kanto, Japan: Reactivation of subducted fracture zone?

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[1] A detailed investigation of the hypocenter distribution beneath Kanto, Japan, reveals a NW-SE-trending linear alignment of seismicity within the subducted Pacific slab. We estimate the 3D seismic velocity structure in the Pacific slab to understand the factors controlling the genesis of such intraslab earthquakes. A narrow low-velocity zone is imaged within the subducted slab over a length of ~150 km, which partly penetrates into the mantle portion of the slab. The low-velocity zone correlates in space with the NW-SE-trending earthquake cluster. A reactivation of hydrated fracture zone formed prior to subduction is probably related to the low-velocity anomaly. Dehydration reactions of the hydrated oceanic mantle as well as the oceanic crust might lower the seismic velocity along the fossil fracture zone, accompanied by intraslab earthquakes. These observations support the hypothesis of dehydration embrittlement as the most viable mechanism for generating intraslab earthquakes. **Citation:** Nakajima, J., and A. Hasegawa (2006), Anomalous low-velocity zone and linear alignment of seismicity along it in the subducted Pacific slab beneath Kanto, Japan: Reactivation of subducted fracture zone?, *Geophys. Res. Lett.*, *33*, L16309, doi:10.1029/2006GL026773.

## 1. Introduction

[2] The occurrence of earthquakes in the subducted slab is an enigma because of the fact that lithostatic pressure at such depths appears to be too high for any brittle fracture. Dehydration embrittlement has been proposed as a possible mechanism for triggering intraslab earthquakes. It is accepted that the slab is hydrated prior to subduction principally through infiltration of seawater via normal or transform faulting [e.g., *Kirby et al.*, 1996] and/or through hot-spot magmatism [*Seno and Yamanaka*, 1996]. During subduction, the fluids released by dehydration reactions induce in situ mechanical instability and brittle deformation by increasing pore pressure. Recent studies have suggested a hypothesis that preexisting weak and preferentially hydrated faults are responsible for intraslab earthquakes [e.g., *Jiao et al.*, 2000; *Ranero et al.*, 2005].

[3] In the Kanto district, the Philippine Sea plate is subducting beneath the Eurasian plate from the south and the Pacific plate is descending beneath the Philippine and Eurasian plates from the east. Figure 1 shows the Mesozoic magnetic lineations and fracture zones in the northwestern Pacific Ocean [*Nakanishi et al.*, 1992]. It is inferred that many fracture zones formed by transform faulting are developed on the seafloor of the Pacific plate and subducted beneath the Japanese Islands, resulting probably in a highly heterogeneous structure even in the subducted Pacific slab.

## 2. Hypocenter Distribution of Intraslab Earthquakes Beneath Kanto

[4] Earthquakes that occurred around the Japanese Islands have been precisely and homogeneously located by the Japan Meteorological Agency (JMA) since October 1997, by grace of the unification of waveform data recorded at the nation-wide seismograph network. We have modified the upper boundary of the subducted Pacific plate by *Zhao and Hasegawa* [1993], based on the precisely determined hypocenter distribution. The configuration of the updated upper boundary of the subducted Pacific slab is similar to that by *Zhao and Hasegawa* [1993] but the depth of the slab is estimated to be 10–15 km shallower at depths between 75 km to 150 km.

[5] To know the detailed distribution of intraslab earthquakes we classified intraslab earthquakes relative to the distance from the upper plate interface of the Pacific slab. Figure 2 shows the distribution of intraslab earthquakes that occurred in the distance range of 0–15 km from the upper plate interface of the Pacific slab. These earthquakes mainly include the upper plane seismicity of the double seismic zone [e.g., *Hasegawa et al.*, 1978] but partly include the seismicity in the oceanic mantle that occurred between the upper and lower planes. The most remarkable feature is a NW-SE-trending linear alignment of seismicity along A-A′, which is distributed obliquely to the iso-depth contours of the Pacific slab. Such a feature is not clear for earthquakes occurring in the distance range of 15–45 km from the upper plate interface of the Pacific slab (see auxiliary materials), suggesting that the alignment of seismicity may be related to a heterogeneous structure of the shallower portion of the slab.[1]

[6] In this study, we estimate a detailed 3D seismic structure beneath the Kanto district to reveal the heterogeneous structure associated with the alignment of seismicity. The main focus of the paper is the velocity structure within the subducted Pacific slab, which might offer some important insights into the factors controlling the occurrence of

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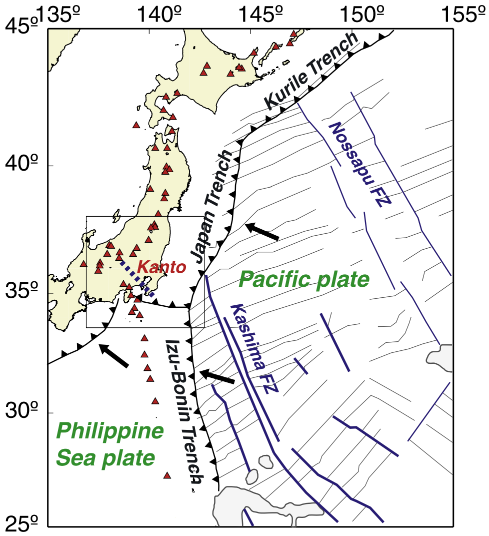


**Figure 1.** Tectonic setting of the northwest Pacific together with the simplified magnetic lineation of *Nakanishi et al.* [1992]. Red triangles and serrate lines denote active volcanoes and the trench axis, respectively. Blue and thin gray lines show location of fracture zones and magnetic lineation, respectively. Thicker blue lines are the fracture zones whose strikes are shown in Figure 4a. The black rectangle shows the outline of the study area shown in Figure 2. The blue broken line in the rectangle represents the location of the NW-SE-trending seismicity discussed in the text. Relative direction between the subducted Pacific and Philippine Sea plates and the overriding plates are indicated by the arrows [*Seno et al.*, 1996].

intraslab earthquakes, besides verifying the hypothesis of dehydration embrittlement.

## 3. Seismic Velocity Structure Within the Pacific Slab

[7] A large number of high-quality P- and S-wave arrival times generated from 4,698 earthquakes were used in the travel-time tomography. We picked the arrival times for 3,250 earthquakes that occurred during the period from January 2001 to December 2005 and obtained 333,627 P- and 214,907 S-wave arrival times. In addition, the arrival times picked by the JMA (29,907 P- and 19,664 S-wave arrivals) were used for 1,448 earthquakes with depths greater than 100 km that occurred between October 1997 and December 2000. The latter data set offers a better ray coverage for the deeper part of the study area. A total number of 697 seismograph stations were used in this study. All of the stations are equipped with three-component seismometers. The data reading accuracy is 0.05–0.1 s and 0.1–0.2 s for P- and S-wave arrivals, respectively. See auxiliary materials for details on distributions of hypocenters and seismograph stations.

[8] In this study, we used the 3-D tomographic method of *Zhao et al.* [1992] to determine 3D P- and S-wave velocity structures beneath Kanto. In the inversion crustal discontinuities and the updated upper boundary of the Pacific slab were taken into account. The velocity structure used in the JMA routine work [*Ueno et al.*, 2002] was adopted as an initial P-wave velocity model. An initial S-wave velocity model was calculated by assuming a constant Vp/Vs value of 1.73. Grid nodes with the horizontal interval of 0.25° and the vertical interval of 10–30 km were set in the model space. The final results were obtained after five iterations. The root mean square of arrival-time residuals for the initial model, 0.37 s for P wave and 0.60 s for S wave, were reduced to 0.25 s and 0.44 s, respectively, upon optimization.

[9] Figure 3a shows a P-wave velocity perturbation along a curved surface 10 km below the upper plate interface of the Pacific slab. The subducted Pacific slab is generally imaged as a high-velocity anomaly, which is consistent with previous studies [e.g., *Nakajima et al.*, 2001; *Wang and Zhao*, 2006]. Low-velocity zones are, however, locally imaged even within the subducted slab. Beneath Kanto, a prominent low-velocity zone with NW-SE strike is detected over a length of ~150 km mainly at depths greater than ~100 km. The low-velocity zone is well recognized also in vertical cross sections and is evidently located within the subducted Pacific slab at depths of 100–150 km (Figures 3b and 3c). It penetrates to at least 20–30 km below the upper plate boundary of the Pacific slab and reaches depths of the lower plane of the double seismic zone, that is, the mantle portion of the slab. Interestingly, the narrow low-velocity zone correlates spatially with the NW-SE-trending earthquake cluster within the Pacific slab. It is noted that S-wave velocity perturbation shows a similar feature and results of resolution tests demonstrate the reliability of the low-velocity zone (auxiliary materials).

## 4. Discussion

[10] Our observations reveal a clear relationship between the velocity structure and seismic activity within the Pacific slab. A possible candidate is the subduction of seamounts which are probably more hydrated than the surrounding

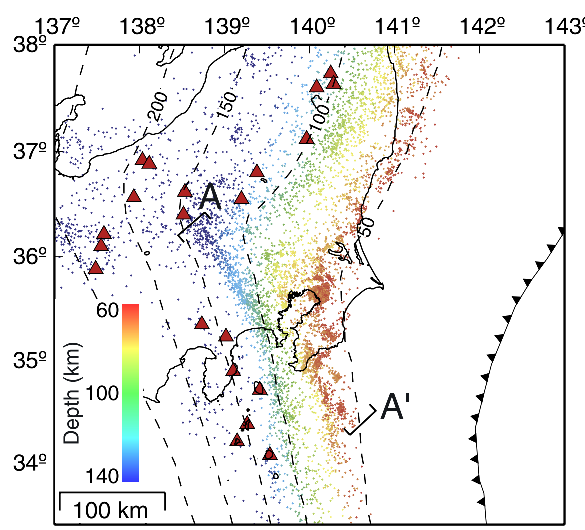


**Figure 2.** Hypocenter distribution of earthquakes that occurred in the distance range of 0–15 km below the upper interface of the Pacific slab in the period from 1997 to 2005. The updated iso-depth contours of the subducted Pacific plate are shown by dashed curves with an interval of 50 km.

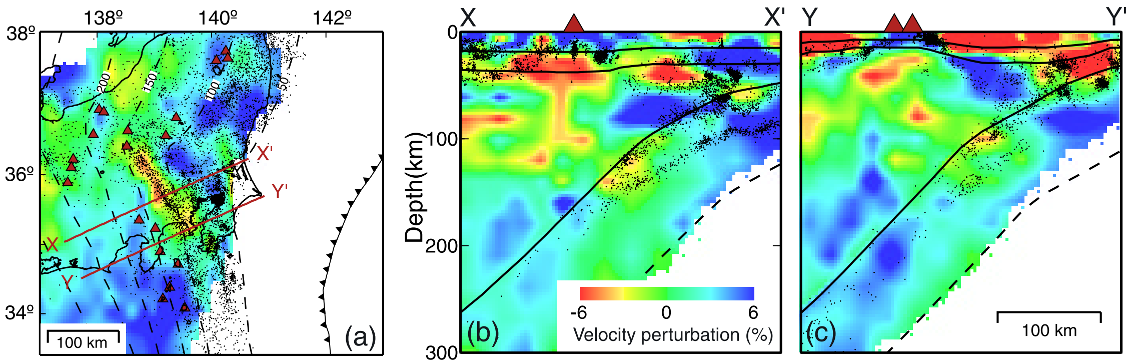


**Figure 3.** (a) P-wave velocity perturbation along a curved surface 10 km below the upper plate interface of the Pacific slab. Dots represent the hypocenters plotted in Figure 2. (b) Vertical-cross section of P-wave velocity perturbation along line X-X′ and (c) that along line Y-Y′. Dots represent earthquakes that occurred within a distance of 10 km from the profile. Solid curves show the seismic velocity discontinuities adopted in the tomographic inversion. The regions with number of rays greater than 1,000 are shown, where the results of checkerboard resolution tests are well recovered (see auxiliary materials).

slab. *Yamazaki and Okamura* [1989] indicated that seamounts with a width of ~30 km are subducted around the Japanese Islands, which are roughly comparable to the width of the observed low-velocity zone. Many seamounts might have been subducted beneath Kanto, followed by possible seismic activity associated with the subducted seamounts, as observed in the Nazca slab [*Kirby et al.*, 1996]. However, it is not evident that a long seamount chain has been successively subducted over a length of ~150 km.

[11] The strike of the low-velocity zone corrected for the slab dip is ~N45°W, while that of major fracture zones developed in the Pacific plate ranges from N30°W to N65°W (Figure 4a), implying that a fracture zone formed prior to subduction is related to the low-velocity zone within the slab. Hence we infer that dehydration reactions along a preexisting fracture zone are responsible for the low-velocity anomaly. A penetration of the low-velocity anomaly to 20–30 km below the slab interface indicates that, along the fracture zone, the shallow portion of the oceanic mantle is hydrated prior to subduction, as observed along the Tydeman fracture zone near the Mid-Atlantic Ridge [*Calvert and Potts*, 1985]. Intensive dehydration reactions might have occurred during the progressive metamorphism along the hydrated fracture zone at depths greater than ~100 km, which in turn lowers the seismic velocity and facilitates intraslab earthquakes along it. The low-velocity anomaly at 20–30 km below the slab interface is probably due to the dehydration of serpentinized oceanic mantle [*Yamasaki and Seno*, 2003], while that close to the slab interface may be attributable to the dehydration of the oceanic crust. Since the dehydration of the oceanic crust generally occurs at shallower depths than the depths where the low-velocity zone is imaged [e.g., *Yamasaki and Seno*, 2003], thermal recovery of the subducted Pacific slab might be slow due to the existence of the Philippine Sea slab in this region, which shifts the dehydration reactions to greater depths along the Pacific slab.

[12] Figure 4b shows nodal-plane poles of the earthquakes that occurred along the inferred fracture zone. Since these earthquakes are expected to have a predominant orientation of fault planes sub-parallel to the strike of the fracture zone, it is likely that the nodal-plane poles distributed along the strike of the fracture zone are the poles of auxiliary fault planes rather than those of actual fault planes. Therefore, the poles distributed in the SW direction probably correspond to the poles of actual fault planes. A scattered distribution of the poles corresponding to actual fault planes might suggest that fault planes with a different orientation are distributed within the fracture zone and/or that some earthquakes occur off the predominant fault plane of the fracture zone.

[13] Most focal mechanisms of the earthquakes occurring along the fracture zone show a sub-horizontal T-axis in the NE-SW or N-S direction (Figure 4c), which are different from those in the NE Japan arc and the Izu-Bonin arc where a down-dip P axis and a mixture of down-dip P and T axes are generally observed [e.g., *Ishida*, 1992; *Igarashi et al.*, 2001; *Christova*, 2005]. The study area includes the arc-arc junction where the maximum dip direction of the slab rapidly changes, roughly E-W in NE Japan and NE-SW in Izu-Bonin. The dip of the subducted slab also changes significantly from north to south along the Izu-Bonin arc; ~40° in the north and almost vertical in the southernmost part [e.g., *van der Hilst and Seno*, 1993]. These effects might have caused the southerly or southwesterly stretch in the upper portion of the slab, and consequently earthquakes with T axis in the NE-SW or N-S direction could occur along the weak fracture zone under such a stress regime.

## 5. Conclusions

[14] This paper reveals an obvious correspondence between the linear alignment of seismicity and the narrow low-velocity zone within the subducted Pacific slab. The low-velocity zone is distributed over a length of ~ 150 km and penetrates to 20–30 km below the upper plate boundary of the Pacific plate. Dehydration along the preexisting fracture zone might be responsible for the low-velocity anomaly. Our observations support the hypothesis of dehydration embrittlement for the genesis of intraslab earthquakes, with implications for hydration of the mantle portion of the slab by faulting prior to subduction. Further work could possibly involve a precise determination of hypocenters and focal mechanisms in the cluster as well

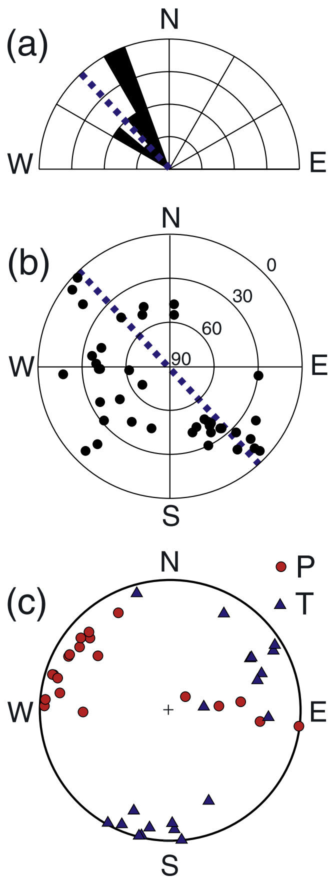


**Figure 4.** (a) Rose diagram of the strike of fracture zones shown by thick blue lines in Figure 1 (black). The blue broken line shows the strike of the linear alignment of seismicity along A-A′ in Figure 2, which is corrected for the slab dip to compare with the strike of fracture zones of the incoming oceanic slab, following the approach of *Jiao et al.* [2000]. (b) Fault plane solutions for 20 earthquakes that occurred along A-A′, which were determined by the JMA. Each fault plane solution is rotated by an angle equal to the local slab dip at the location of the event. Solid circles are poles of two nodal planes in every fault plane solution. The blue bashed line is the same as in Figure 4a. (c) Lower hemisphere projection of P and T axes of the fault plane solution for the earthquakes shown in Figure 4b.

as a detailed investigation of seismicity near the trench. These are, however, beyond the scope of this paper.

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